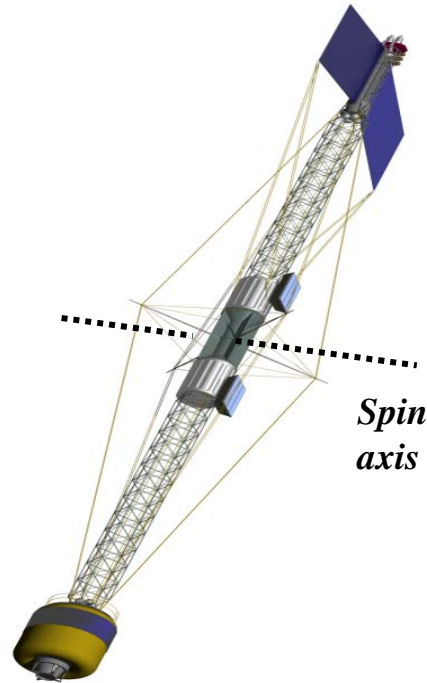


# ***Future Spacecraft design and artificial gravity***



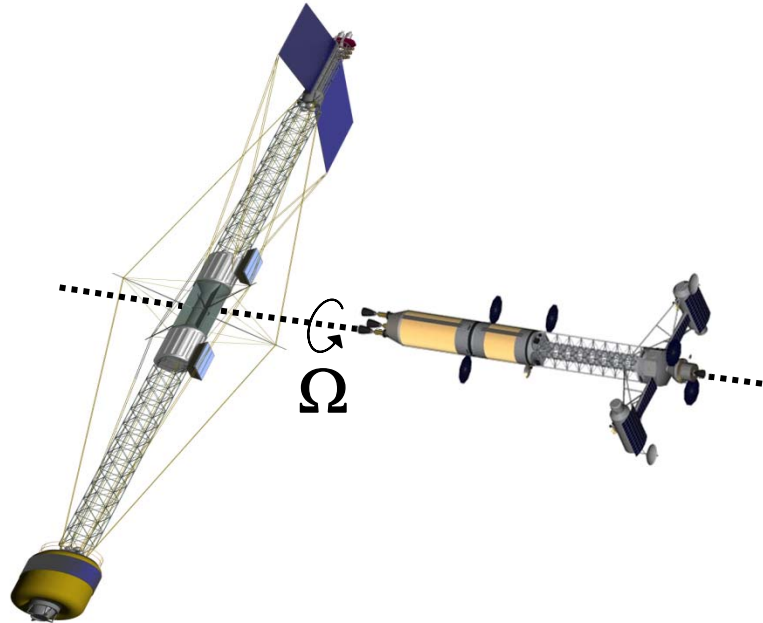
***Peter Norsk, M.D., dr. med.***

***USRA & NASA Johnson Space Center***

# 2014 Artificial Gravity Workshop

Chairs:

William Paloski, Ph.D., and John B. Charles, Ph.D.



## White Paper

**Ames Research Center, February 19 – 20, 2014**

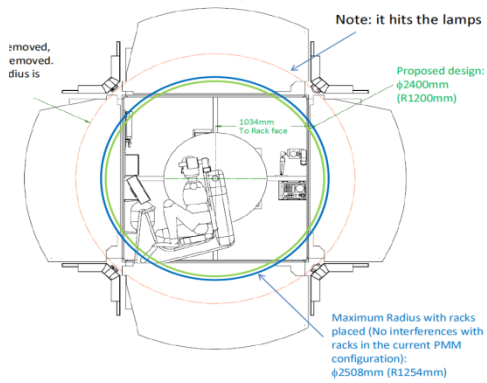
## Editorial Board:

Peter, Norsk, M.D., Maneesh Arya, Ph.D., LaRona Smith, RN, MSN,  
Ronita Cromwell, Ph.D., Justin Kugler, Charlene Gilbert, and David  
Baumann, M.Sc.

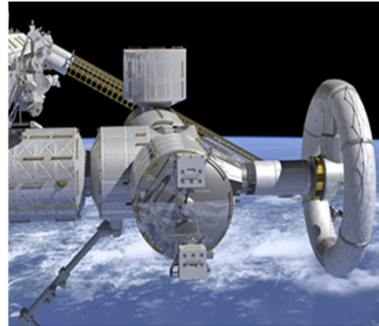
Design and engineering



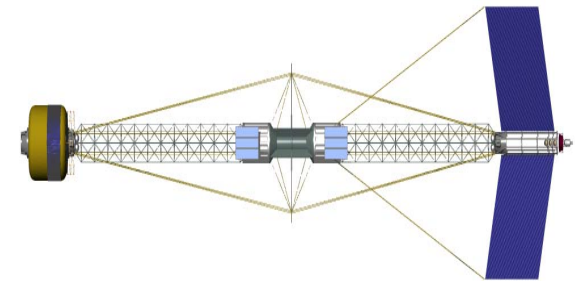
# AG Space Scenarios



Intra-vehicular

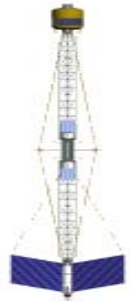


Part of Vehicle



Whole Vehicle

# Whole vehicle rotation configurations

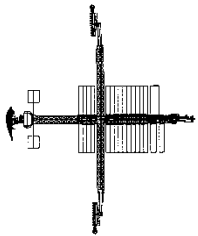


**“Fire Baton”**

- Hab counterweighted by reactor/power conversion systems
- Entire vehicle rotates
- Vehicle pointing provides majority of thrust vector control (TVC)

- *No rotating joints, power connections, fluid connections, etc.*
- Power conversion systems operate in g-“field”

- *Vehicle angular momentum must be continuously vectored for TVC*
- Thermal radiators in g-“field”
- Crew ingress/egress

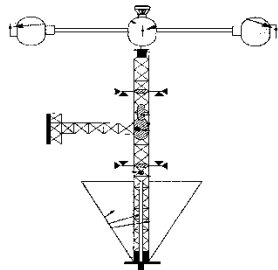


**“Ox Cart”**

- Hab counterweighted by reactor/power conversion systems
- Thrusters, despun, gimbaled for TVC

- *Thrust vectoring decoupled from rotational angular momentum*
- Power conversion systems operate in g-“field”

- *Megawatt-level power, prop transfer across rotating joints*
- Potential cyclical loading of rotating joints
- Thermal radiators in g-“field”
- Crew ingress/egress

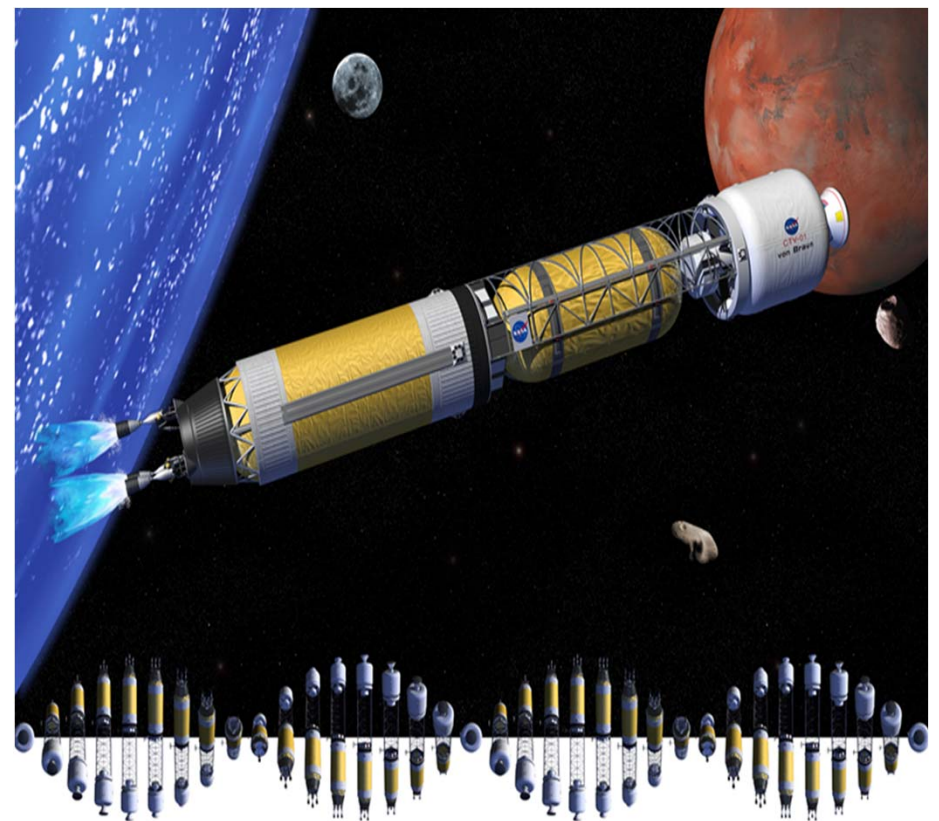
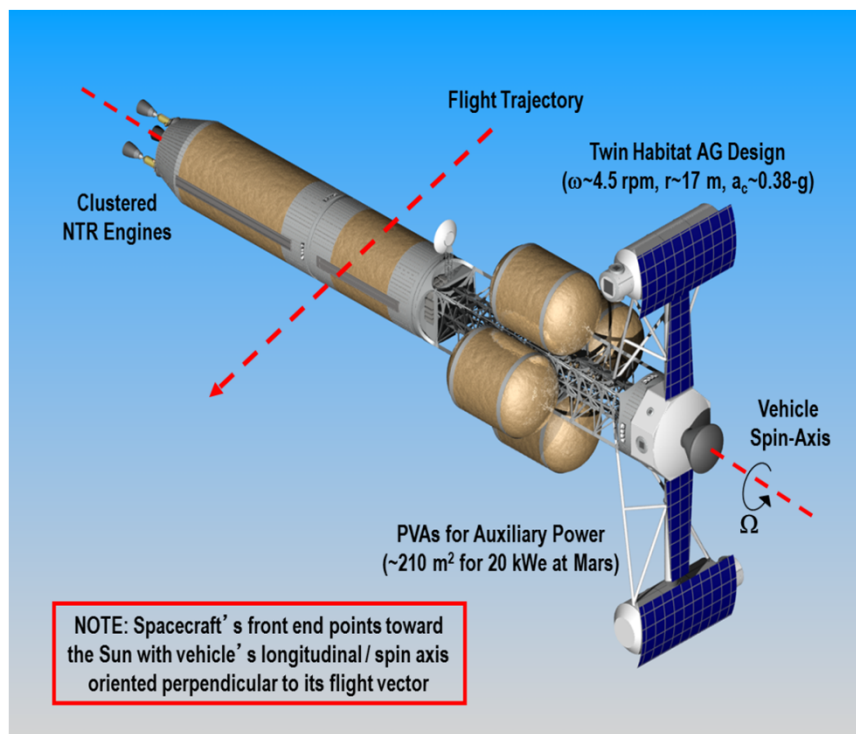


**“Beanie Cap”**

- Split habitation volumes for counterweights
- Reactor/power conversion systems, thrusters in zero-g
- Thrusters gimbaled for TVC

- *Thrust vectoring decoupled from rotational angular momentum*
- Thermal radiators in zero-g

- *Inefficiencies in duplicating habitation systems, crew transfer between them*
- Potential cyclical loading of rotating joints
- Power conversion systems operate in zero-g
- *Kilowatt-level power transmission across rotating joints*



# Life Science Requirements

What has already been done?





# AG-Human models (Ground & Space)

## Rotating

- Short-radius – intermittent
- Long-radius - intermittent
- Rotating room – continuous

## Non-rotating (linear acceleration)

- Lower Body negative Pressure (LBNP)

- Exercise

  - Treadmill

  - Resistive

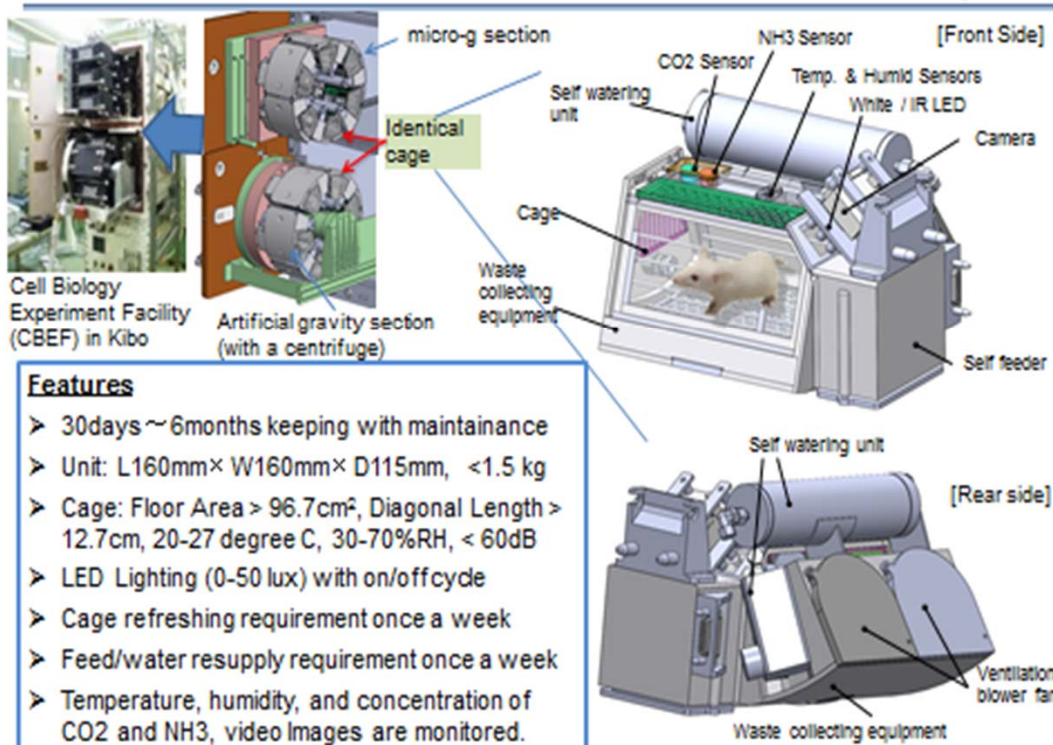
  - Aerobic

  - LBNP + Exercise



## AG-Animal Models (Ground & Space)

### Overview of Mouse Habitat Cage Unit





# Short-Radius Intermittent centrifugation



# Summary: Effectiveness of AG Prescription

	main hypotheses*	finding	comment
<b>Bone</b>	↔ bone mineral density ↑ bone homeostasis	as expected not supported	short duration insufficient loading?
<b>Muscle</b>	↑ strength ↑ fiber-type homeostasis ↓ muscle atrophy	supported supported supported	
<b>Cardio</b>	↑ orthostatic tolerance ↑ sympathetic response ↑ aerobic capacity	supported supported supported	
<b>Neuro</b>	↔ CDP, OCR ↔ SVV ↑ proprioceptive reflexes	as expected not supported supported	no adverse response spatial disorientation?
<b>Immuno</b>	↑ stress marker response	not supported	no Δ either group
<b>Psych</b>	↔ cognitive performance	supported?	↓ trend, but low n

\*expected outcome of Treatment Subjects when compared to Control Subjects



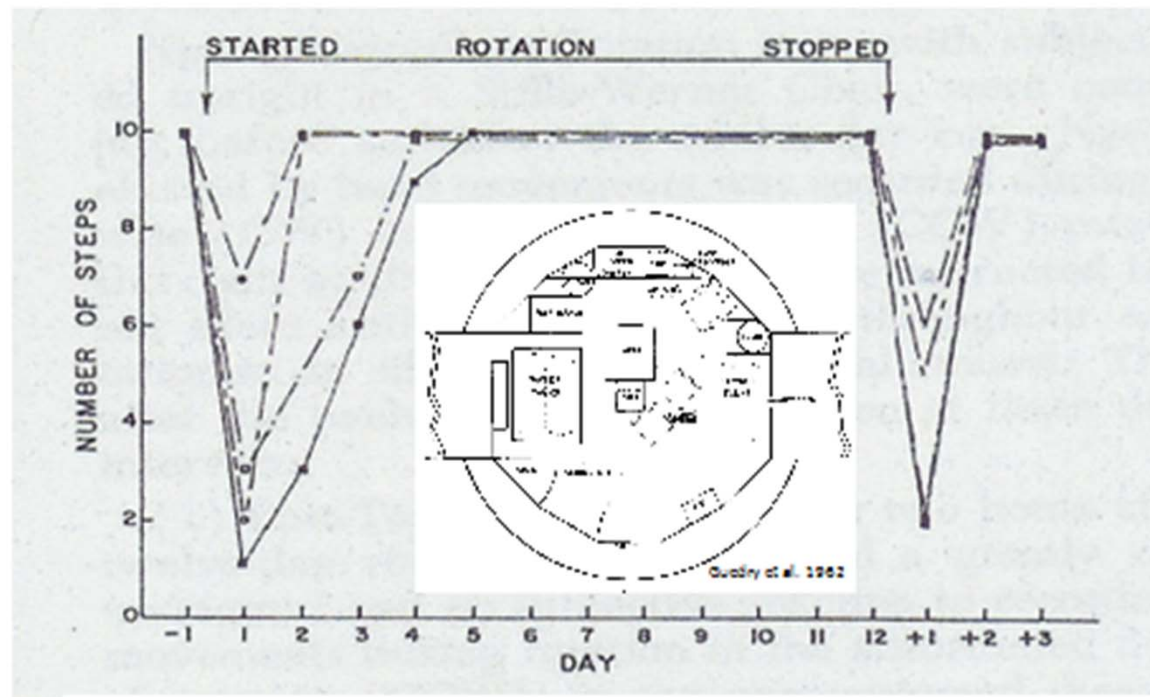
# Long-Radius Intermittent centrifugation





# Rotating Room Continuous Centrifugation

## Adapting to a Slow-Rotating Room



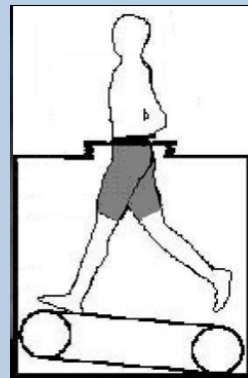




# Non-Rotating, Linear Models



## Resistance Exercise



## Aerobic Exercise



Exercise in  
LBNP

# Gravity-Bed: Method to Provide Balance Training During Bed Rest



**Backpack frame freely moving on air-bearings**

Oddsson et al. A rehabilitation tool for functional balance using altered gravity and virtual reality  
*Journal of NeuroEngineering and Rehabilitation* 4:25, 2007

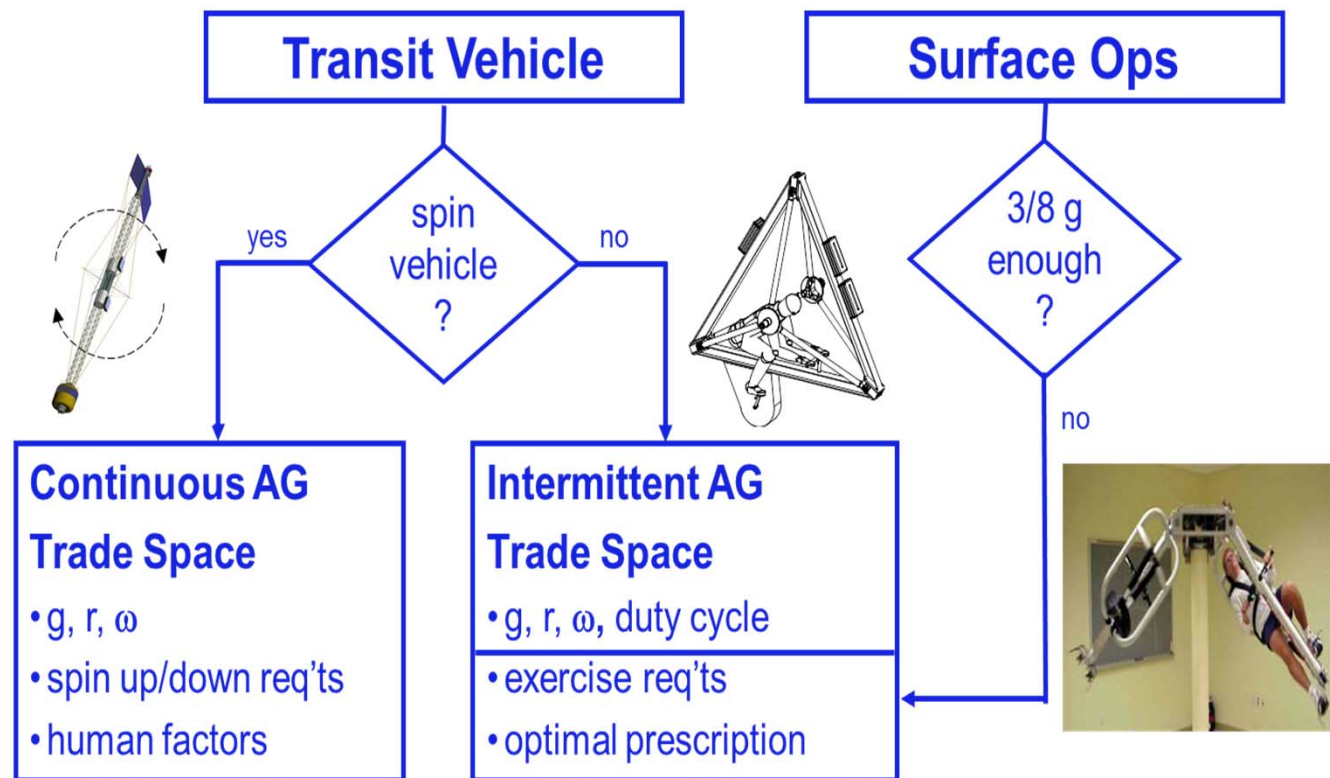


# Future Plans



# AG Decision Tree

**Objective: Evidence Base to Guide Program Decisions**





## Research Approach: Ground Based

AG-type	Species	Low-G Sim.	Research Question
Continuous (Bioreactor)	Cell cultures		Bioreactor Dose-response 0–1 G (Biomarkers, OSaD, Gene/omics)
Intermittent (Short Radius)	Animals	HU-Suspension	- Dose-response G protection (SM, MS, CV)
	Humans	Bed Rest	- Dose-response G-protection (SM, MS, CV)
Intermittent (Long Radius)	Humans	Bed Rest	- Dose-response G-protection - Effects of gravity gradient (SM, MS, CV)
Continuous (Long Radius)	Animals	± HU-Suspension	- Dose-Response for AG-Protection - AG-Adaptation (SM, CV, VIIP)
	Humans	None	- AG-adaptation vs. t, $\omega$ , etc. - (SM, CV, BHP)
	Humans		± Bed rest - Protective effects of AG (SM, CV, MS, AG-level determined from animal studies)



## Research Approach: Space Based

AG-type	Species	Mission	Research Question
Chronic (Small Cent.)	Cell cultures	ISS	Dose-Response 0–1 G (Biomarkers, OSaD, Gene/omics)
Chronic (Animal Cent.)	Animal	ISS	Dose – Response 0–1 G (SM, MS, CV, VIIP)
Intermittent  (Short Radius)	Humans	ISS, EAM, Cmcl or other providers  (Intra/Extra)	Testing of AG from Grd Research  (SM, MS, CV, VIIP, IM, OSaD, BHP)
Chronic (Large Radius)	Humans	Vehicle-Cent.	Testing of AG from Grd Research (SM, MS, CV, VIIP, IM, OSaD, BHP)

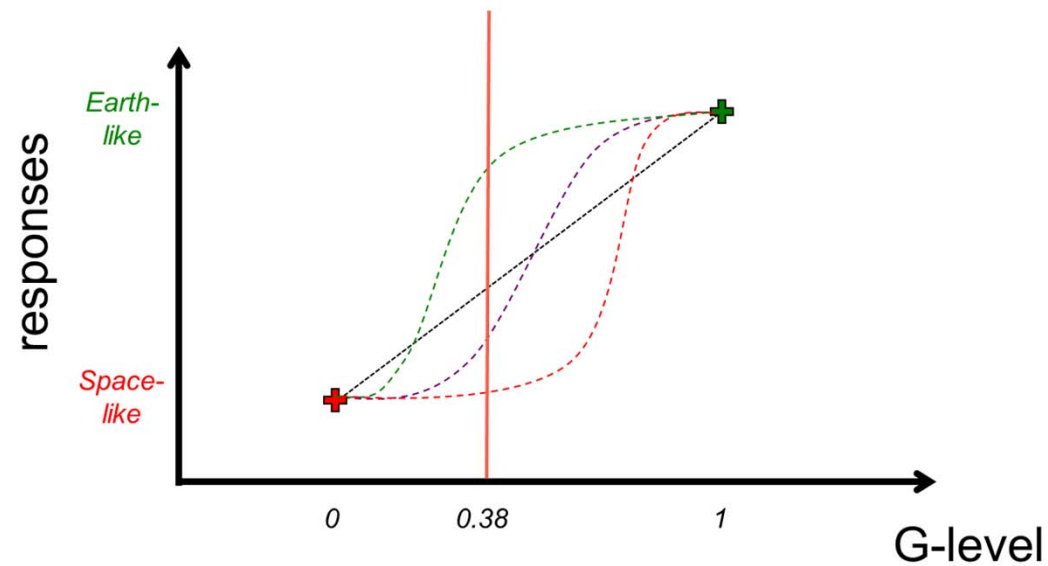
# G-thresholds and Planetary G- Protection



## Low-G (Lunar/Martian) Research Simulation Approach

Question: How well do Lunar and Martian G's protect Astronaut health?

### *Physiological Responses to Hypogravity?*





## Hypogravity Analogs

### Ground based

#### Acute (s – hrs):

- Parabolic flights (Parabol)
- Low Degree Head-up tilt (Low Deg HUT)
- head-out graded water immersion (Graded WI)
- Supine/head-down tilted centrifugation (Sup/HDTCent)
- Whole-body weighted garment water immersion (WeightedWI)
- Lower body positive pressure (LBPP)

#### Longterm (days – months):

- Low Degree Head-up bed rest (Low Deg HUBR)
- Head-out graded dry immersion (Graded DI)
- Supine/HDT long-arm centrifugation (Sup/HDTCent)

### Space based

#### Acute (hrs):

- Short-arm centrifugation (ShortSpaceCent)

#### Longterm (days to mos):

- Short-arm animal centrifugation (AnimalSpaceCent )
- Long-arm centrifugation (LongSpaceCent)

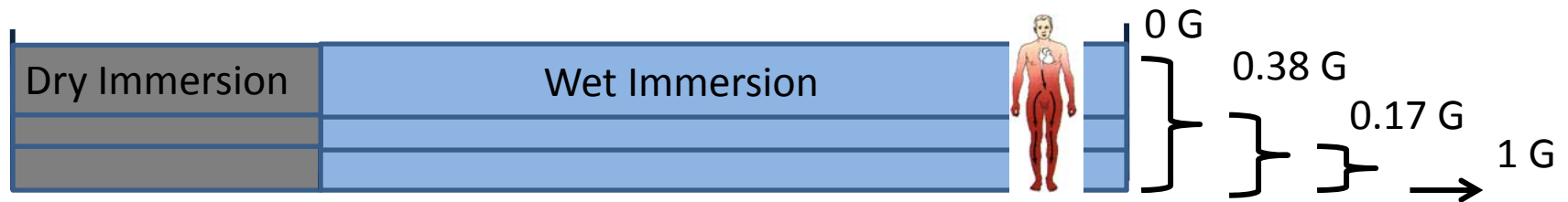


**A Vision:**

# Hypogravity Analog Model (HAM)

**Resting Habitat**

**Ambulatory Activities**







# Not a new concept!



# Conclusions

- Broad interest to pursue AG
- Continuous whole space habitat spinning possible
- Before 2022, life science requirements should be defined
- Three scenarios: Intra -, extra-, & whole-vehicle rotation
- Critical research path (international):
  - 1) Animal ground and space,
  - 2) human ground,
  - 3) cell culture ground and space

Thank You